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(54) **HALL ELEMENT SIGNAL CALIBRATING IN ANGLE SENSOR**

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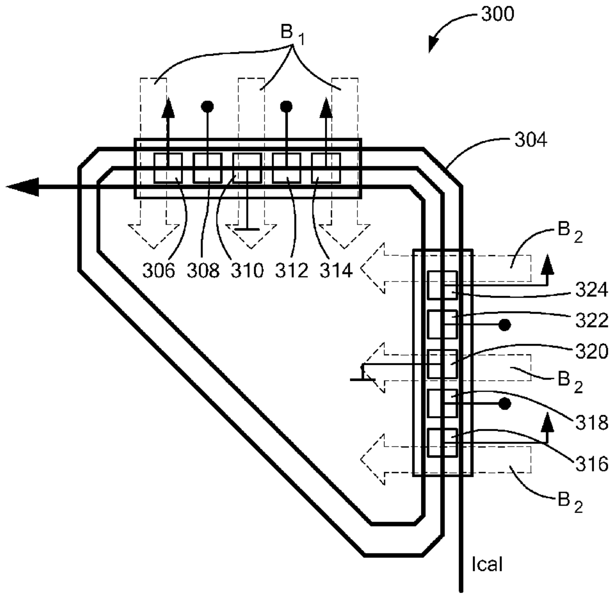
(57) **ABSTRACT**

In one aspect, an angle sensor includes a first Hall element disposed on a first axis, a second Hall element disposed on a second axis perpendicular to the first axis and a conduction path having a first portion extending parallel to the first axis and a second portion parallel to the second axis. The conduction path is configured to conduct a calibration current that generates a first magnetic flux density measured at the first Hall element and a second magnetic flux density measured at the second Hall element. The angle sensor also includes calibration circuitry configured to generate one or more compensation signals based on the first and second magnetic flux densities and to adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor.

33 Claims, 8 Drawing Sheets



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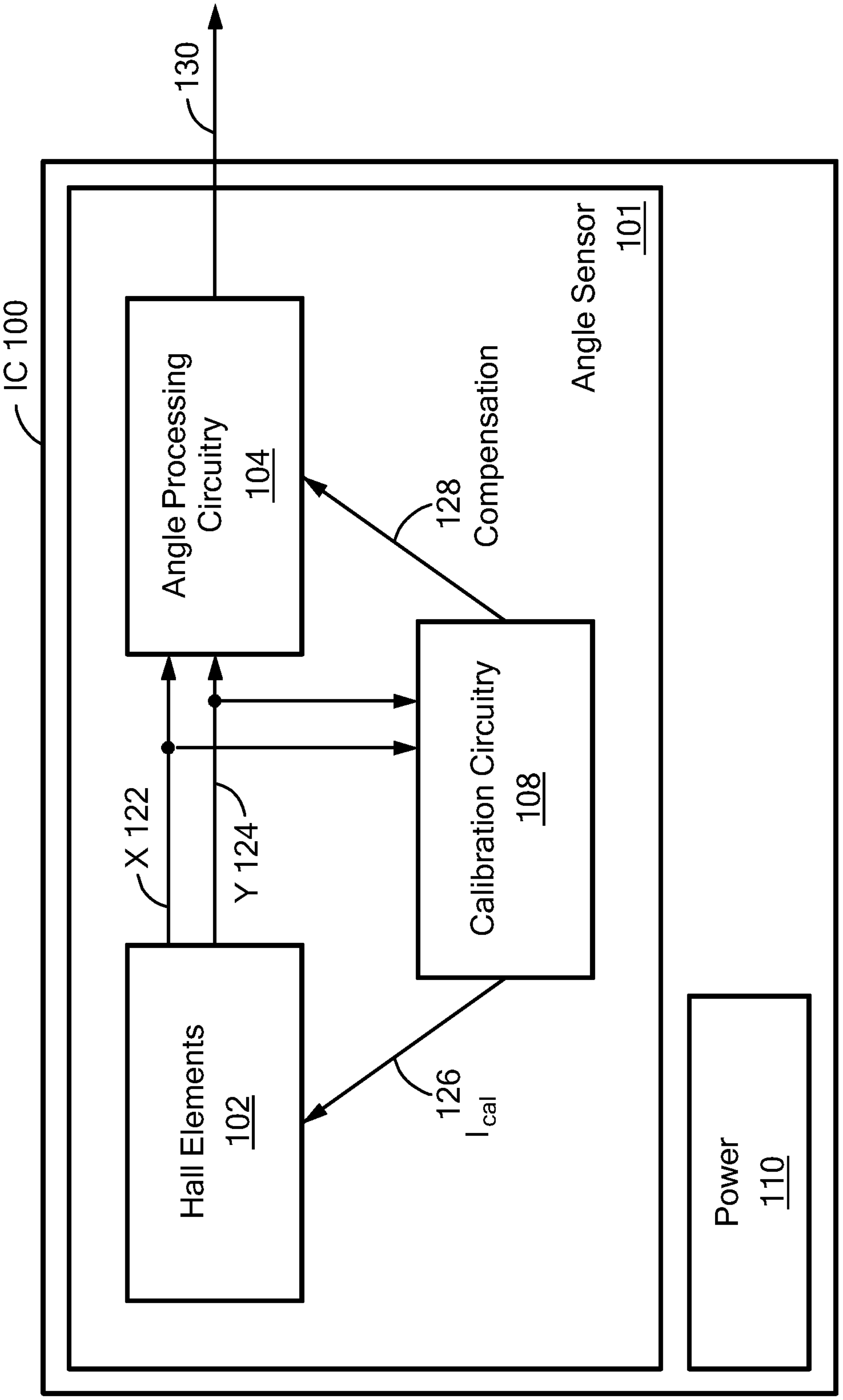
130
IC 100
Angle Sensor
101
Angle Processing
Circuitry
104
128
Compensation
X 122
Y 124
Calibration Circuitry
108
Hall Elements
102
126
I_{cal}
Power
110

FIG. 1

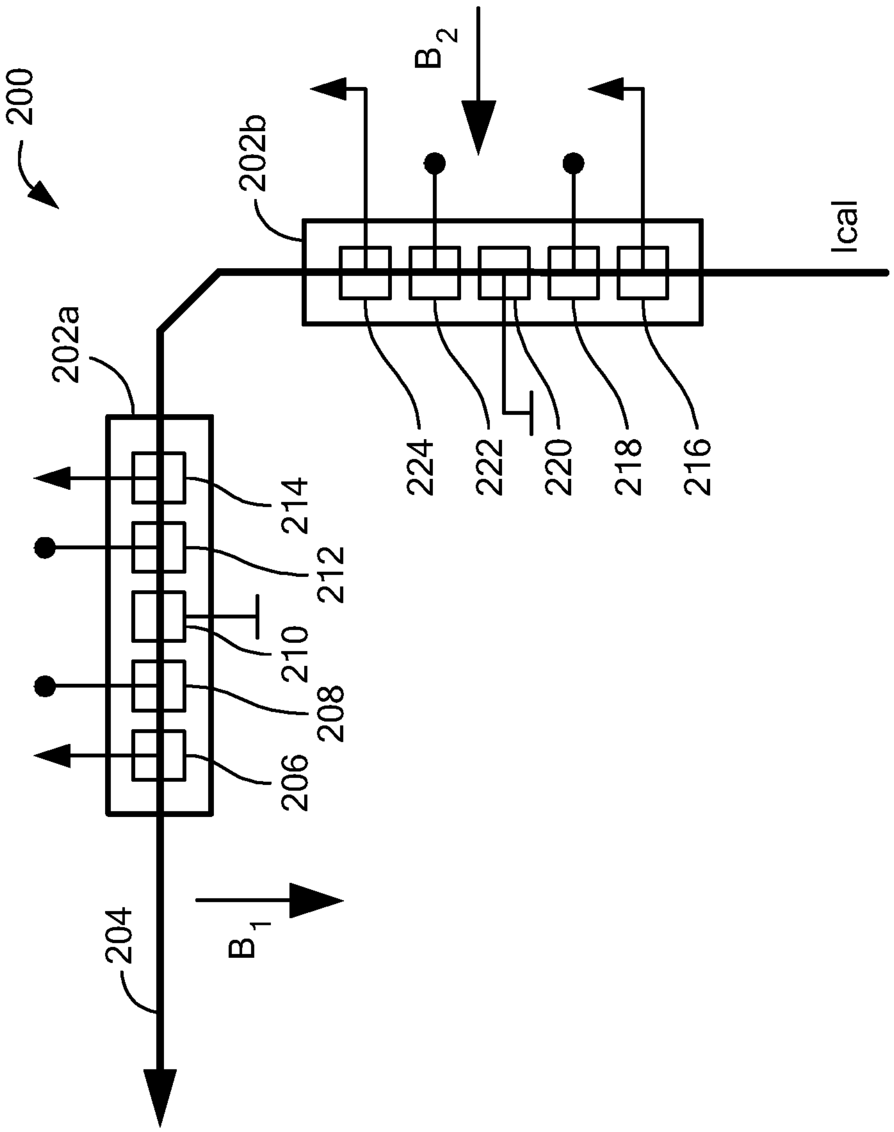
200
202b
B2
Ical
202a
224
222
220
218
216
214
212
210
208
206
204
B1

FIG. 2A

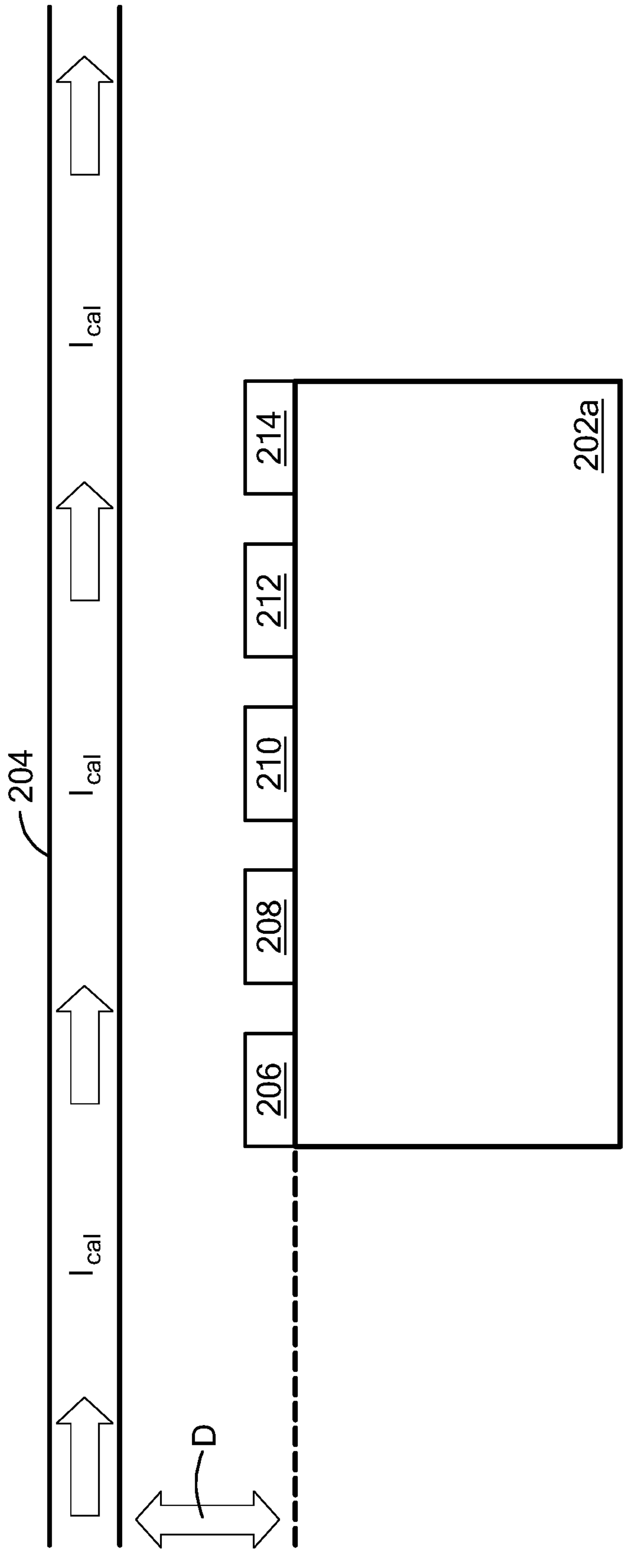

FIG. 2B

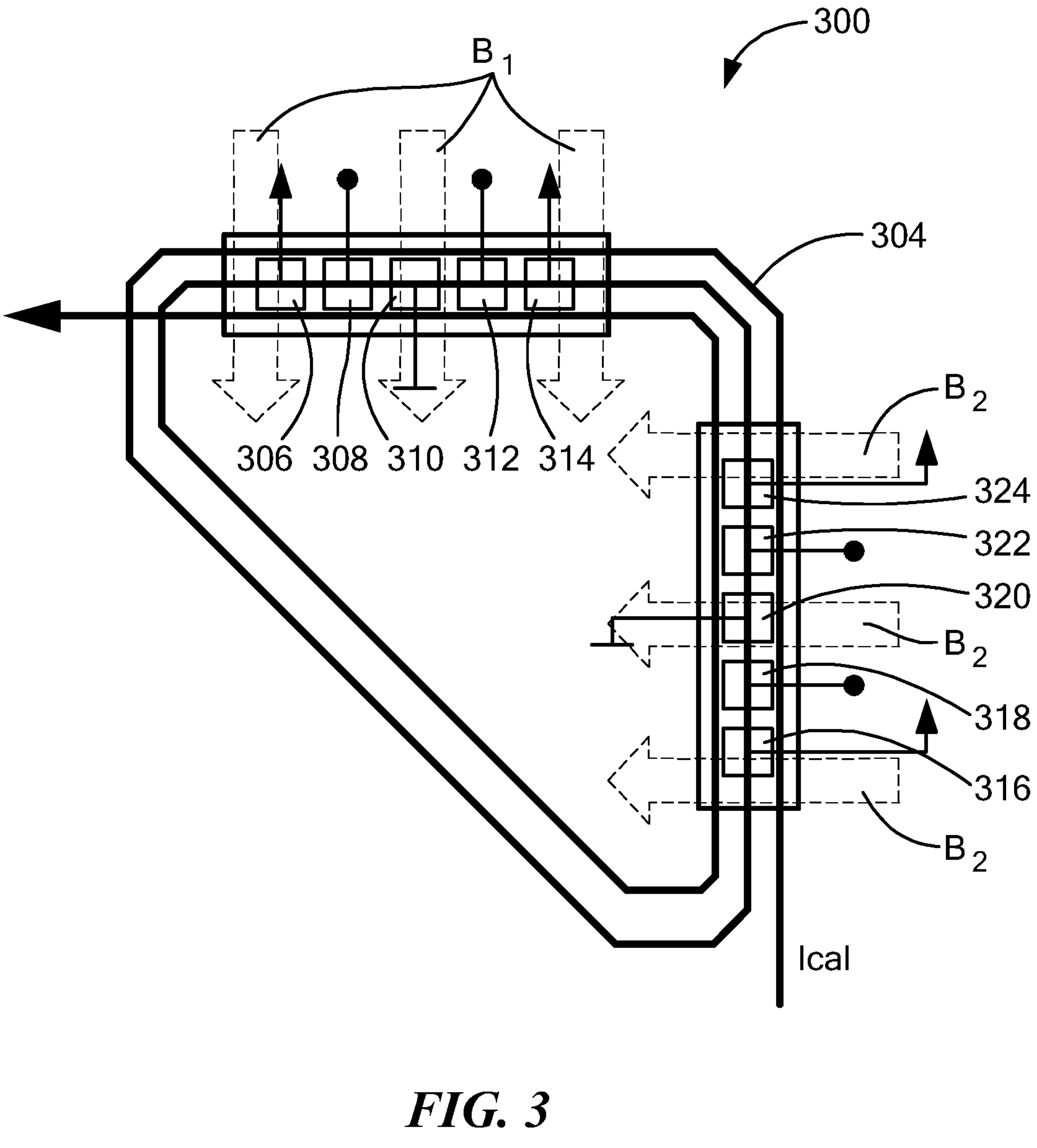

FIG. 3

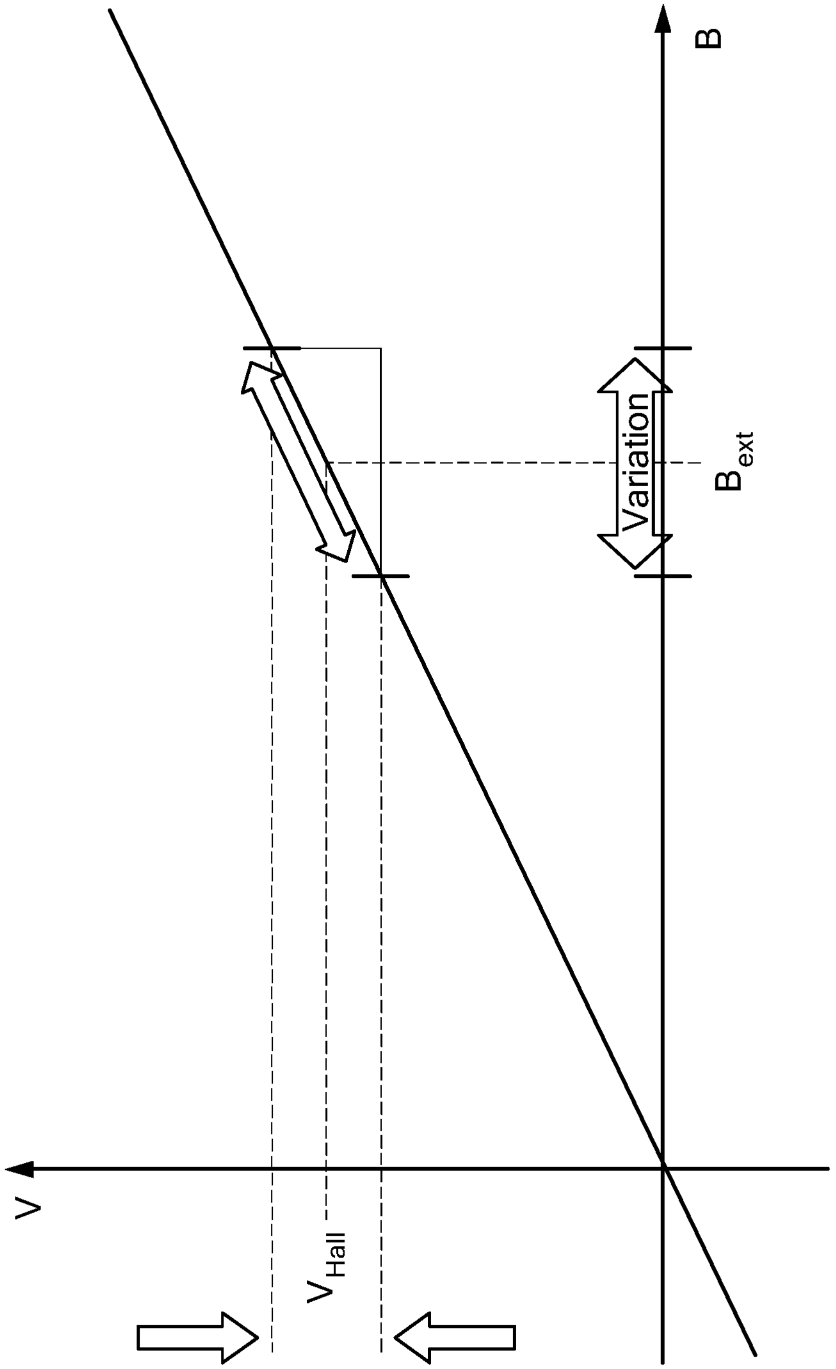

FIG. 4

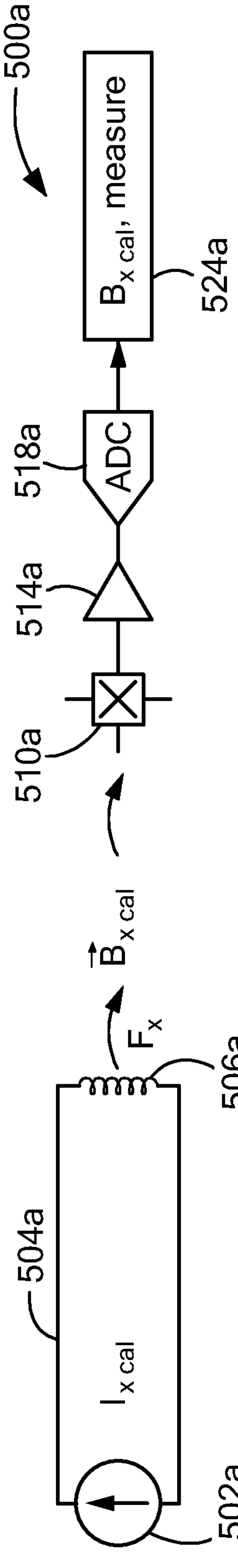

FIG. 5A

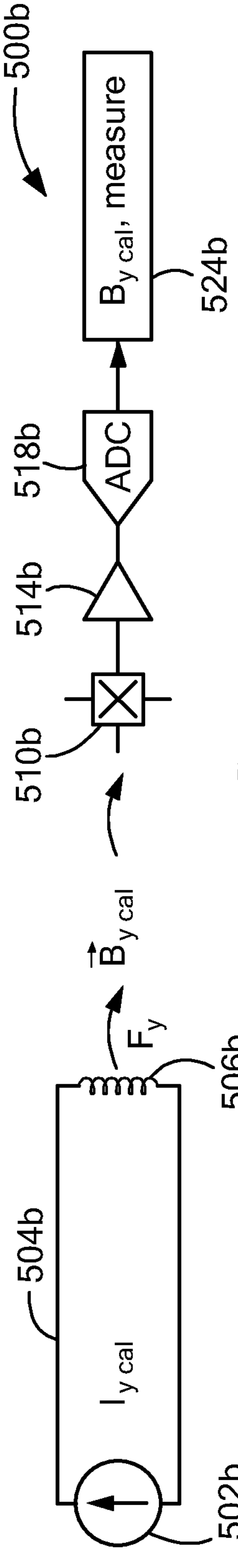

FIG. 5B

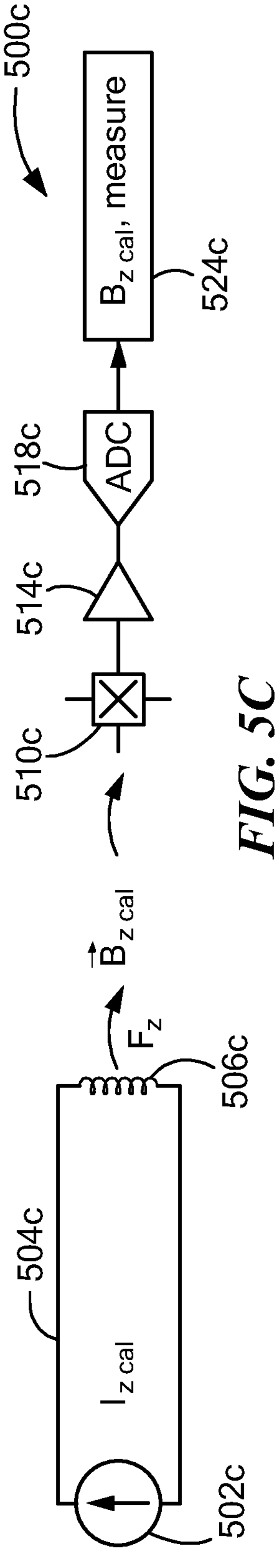

FIG. 5C

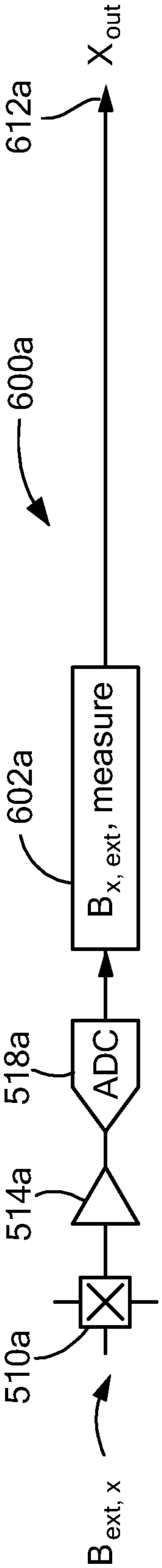

FIG. 6A

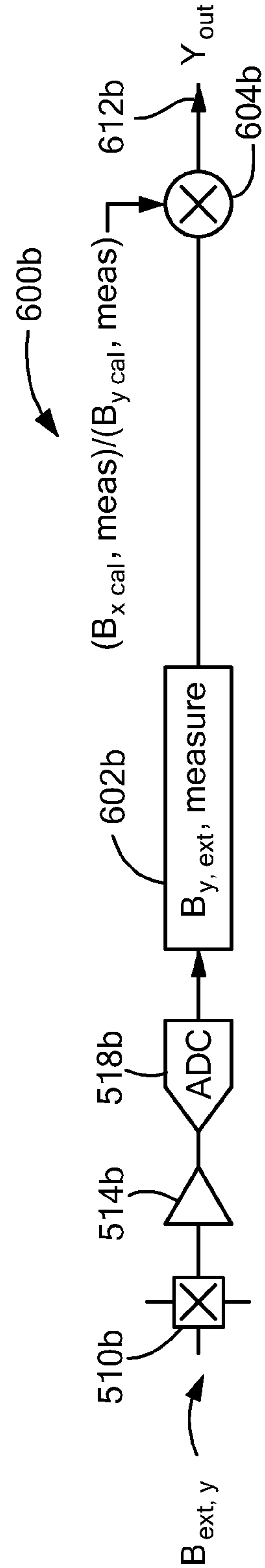

FIG. 6B

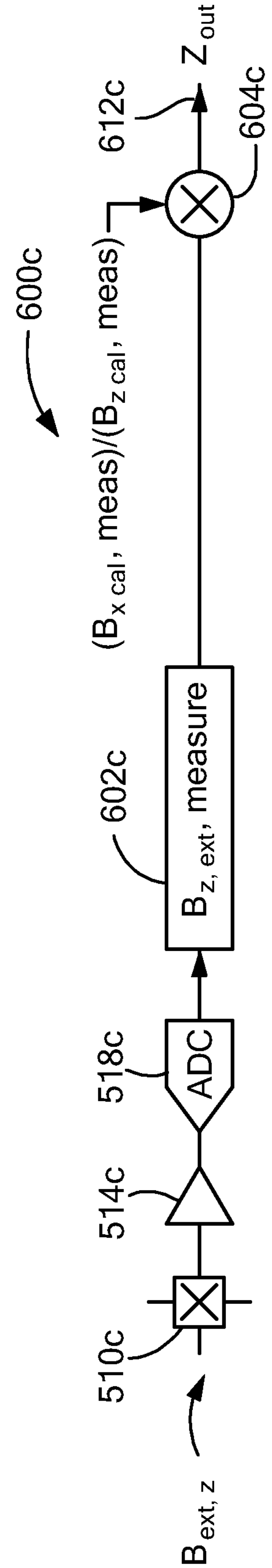

FIG. 6C

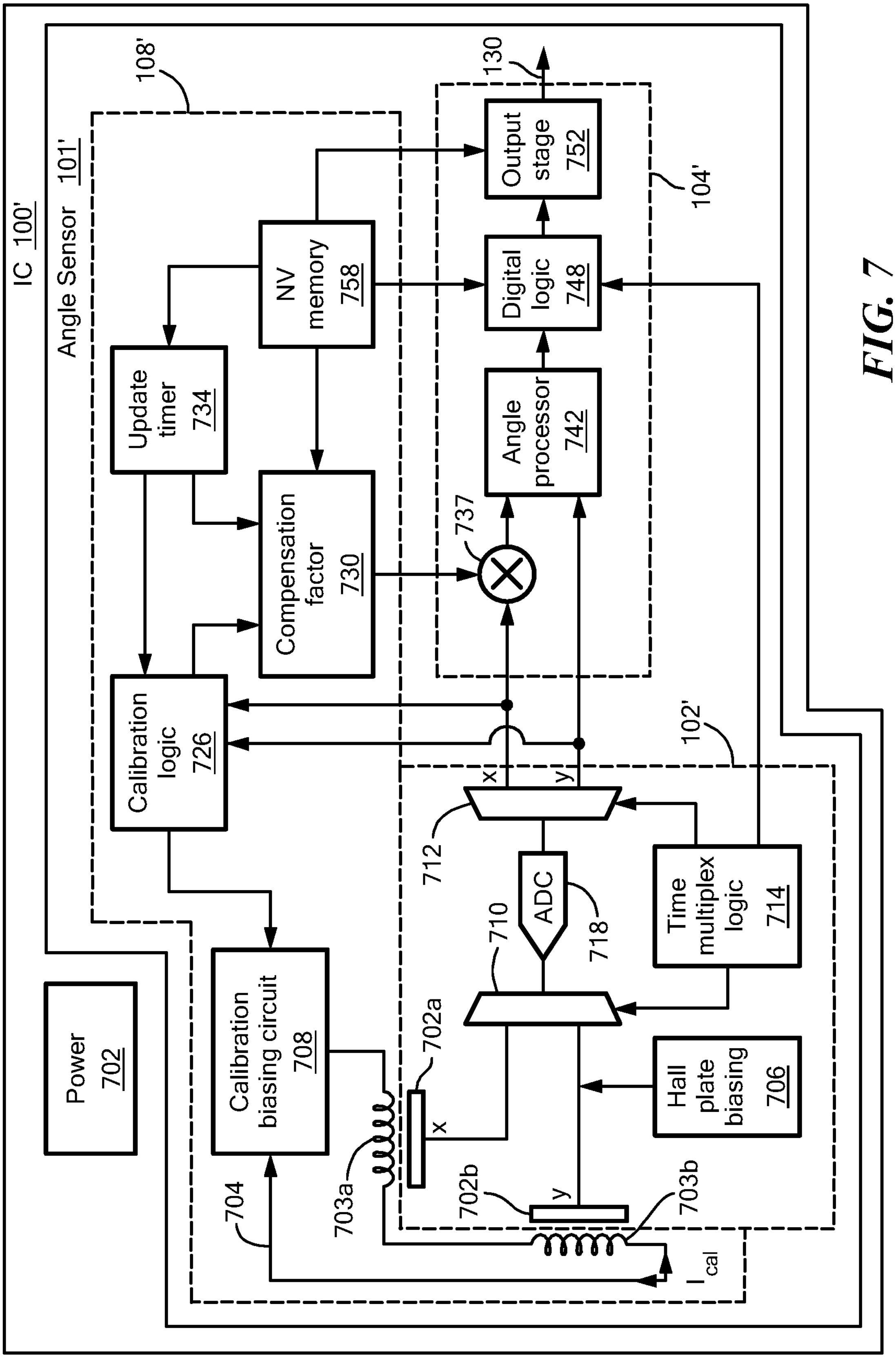
IC 100'
Angle Sensor 101'
108'
104'
102'
130
Output stage 752
Digital logic 748
Angle processor 742
NV memory 758
Update timer 734
Compensation factor 730
737
Calibration logic 726
Calibration biasing circuit 708
Power 702
x
y
712
ADC
718
710
Time multiplex logic 714
Hall plate biasing 706
702a
702b
703a
703b
704
x
y
I_{cal}

FIG. 7

HALL ELEMENT SIGNAL CALIBRATING IN ANGLE SENSOR

BACKGROUND

Typically, a magnetic-field angle sensor measures a direction of a magnetic-field vector through 360° in an x-y plane. In one example, a magnetic-field angle sensor may be used to detect an angular position of a rotating magnet. Some magnetic-field angle sensors may include one or more Hall elements. When signals from Hall elements are not properly calibrated, angle error of the angle sensor increases. Generally, the angle error is defined to be the difference between an actual position of a magnet and a position of the magnet as measured by the angle sensor.

SUMMARY

In one aspect, an angle sensor includes a first Hall element disposed on a first axis, a second Hall element disposed on a second axis perpendicular to the first axis and a conduction path having a first portion extending parallel to the first axis and a second portion parallel to the second axis. The conduction path is configured to conduct a calibration current that generates a first magnetic flux density measured at the first Hall element and a second magnetic flux density measured at the second Hall element. The angle sensor also includes calibration circuitry configured to generate one or more compensation signals based on the first and second magnetic flux densities and to adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor.

In another aspect, a method includes determining one or more compensation signals based on a first magnetic flux density measured at a first Hall element of an angle sensor disposed on a first axis and a second magnetic flux density measured at a second Hall element of the angle sensor disposed on a second axis perpendicular to the first axis and adjusting an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals.

In a further aspect, an angle sensor includes a first Hall element disposed on a first axis, a second Hall element disposed on a second axis perpendicular to the first axis, a first conduction path extending parallel to the first axis, a second conduction path extending parallel to the second axis, and calibration circuitry configured to generate one or more compensation signals based on the first and second magnetic flux densities and adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor. The first conduction path is configured to conduct a first calibration current that generates a first magnetic flux density measured at the first Hall and the second conduction path is configured to conduct a second calibration current that generates a second magnetic flux density measured at the second Hall element.

In a still further aspect, an angle sensor includes a first Hall element disposed on a first axis; a second Hall element disposed on a second axis perpendicular to the first axis and a means for calibrating signals from the first and second Hall elements.

DESCRIPTION OF THE DRAWINGS

The foregoing features may be more fully understood from the following description of the drawings. The drawings aid in explaining and understanding the disclosed technology. Since it is often impractical or impossible to illustrate and describe every possible embodiment, the provided figures depict one or more illustrative embodiments. Accordingly, the figures are not intended to limit the scope of the broad concepts, systems and techniques described herein. Like numbers in the figures denote like elements.

FIG. **1** is a block diagram of an example of an integrated circuit (IC) to calibrate signals from Hall elements;

FIGS. **2**A and **2**B are diagrams of vertical Hall elements with a conduction path used to generate magnetic field flux densities;

FIG. **3** is a diagram of planar Hall elements with a conduction path arranged in a coil used to generate magnetic field flux densities;

FIG. **4** is a graph a magnetic field versus Hall voltage;

FIGS. **5**A to **5**C are circuit diagrams used to generate compensation signals;

FIGS. **6**A to **6**C are circuit diagrams to calibrate signals measured from Hall elements using the compensation signals from FIGS. **5**A to **5**C; and

FIG. **7** is a block diagram of an example of a circuit used to calibrate signals from Hall elements.

DETAIL DESCRIPTION

Described herein are techniques to improve angle accuracy of a magnetic-field angle sensor (e.g., on an integrated circuit (IC)) by calibrating signals, on the IC, from Hall elements used in an angle sensor as opposed to a one-time calibration done at an IC manufacturer.

Referring to FIG. **1**, an example of an IC that performs calibration of signals from Hall element is an IC **100**. The IC **100** includes an angle sensor **101** and power **110** that power components on the IC **100** including the angle sensor **101**. The angle sensor **101** includes Hall elements **102**, angle processing circuitry **104** and calibration circuitry **108**.

In one example, the Hall elements **101** are planar Hall elements. In another example, the Hall elements **101** are vertical Hall elements.

The Hall elements **102** in this embodiment include at least two Hall elements that are orthogonal to each other and the angle sensor **101** is a 2D (two-dimensional) angle sensor. For example, at least one Hall element is along an x-axis and at least one Hall element is along a y-axis.

In other embodiments, the Hall elements **102** may include at least three Hall elements that are orthogonal to each other and the angle sensor **101** is a 3D (three-dimensional) angle sensor. For example, at least one Hall element is along an x-axis, at least one Hall element is along a y-axis and at least one Hall element is along a z-axis.

In one example, the Hall elements **102** provide a signal X **122** from at least one Hall element along the x-axis and a signal Y **122** from at least one Hall element along the y-axis. The signals X **122**, Y **124** are sent to the angle processing circuitry **104** and to the calibration circuitry **108**.

In one example, in a first mode, the calibration circuitry **108** provides a calibration current I_{cal} **126** used in calibrating signals from the Hall elements **102**. The calibration current I_{cal} **126** is used to measure the sensitivity of the Hall elements **101**. In particular, the calibration current I_{cal} **126** generates a magnetic flux density that is detected by the Hall elements **102**. The signals X **122**, Y **124**, which are provided by the Hall elements **102**, are used by the calibration circuitry **108** to generate one or more compensation signals **128**. In one example, the calibration current I_{cal} **126** is an alternating current. In one example, a frequency of the calibration current I_{cal} **126** is 100 kHz.

In a second mode, without the calibration current I_{cal} activated, the Hall elements **102** detect a magnetic field and provide the signals X **122**, Y **124**. The angle circuitry **104** uses the compensation signals **128** to calibrate one or more of the signals X **122**, Y **124**. Based on the signals X **122**, Y **124** and the compensation signals **128**, the angle circuitry **104** provides an output signal **130** that includes an angle.

Referring to FIGS. **2**A and **2**B, an example of a circuit configuration used to generate magnetic field flux densities is a circuit configuration **200**. In one example, the circuit configuration **200** includes at least two vertical Hall elements (e.g., a Hall element **202***a* and a Hall element **202***b*) and a conduction path **204**. In one example, the conduction path **204** carries the calibration current **126** (FIG. **1**) and generates a first magnetic field flux density B_1 along the first Hall element **202***a* and a second magnetic field flux density B_2 along the second Hall element **202***b*.

Each Hall element **202***a*, **202***b* includes at least five metal contacts. For example, the Hall element **202***a* includes a contact **206**, a contact **208**, a contact **210**, a contact **212** and a contact **214**, and the Hall element **202***b* includes a contact **216**, a contact **218**, a contact **220**, a contact **222** and a contact **224**.

The contacts **206**, **214** are used to supply power to the Hall element **202***a*. The contacts **208**, **212** are used to measure signals (e.g., a voltage signal) from the Hall element **202***a* and the contact **210** provides a ground to the Hall element **202***a*.

The contacts **216**, **224** are used to supply power to the Hall element **202***b*. The contacts **218**, **222** are used to measure signals (e.g., a voltage signal) from the Hall element **202***b* and the contact **220** provides a ground to the Hall element **202***b*.

The conduction path **204** is separated from the Hall plates **202***a*, **202***b* by a distance D. In one example, the distance D is 1 micron.

The magnetic field flux density generated by the calibration current is:

$$B_{cal} = \frac{1}{r} * \frac{\mu}{2\pi} * I_{cal}.$$

Assuming a 1 micron distance between the Hall element and the conduction path and a 10 mA conduction current, the expected magnetic flux density is 20G and the coupling factor is

$$\frac{B_{cal}}{I_{cal}} \text{ or } 2\text{ G/mA.}$$

Referring to FIG. **3**, another example of a circuit configuration to generate magnetic field flux densities is a circuit configuration **300**. In one example, the circuit configuration **200** includes at least two planar Hall elements (e.g., a Hall element **302***a* and a Hall element **302***b*) and a conduction path **304** in a form of a coil. In one example, the conduction path **204** carries the calibration current **126** (FIG. **1**) and generates a first magnetic field flux density B_1 along the first Hall element **302***a* and a second magnetic field flux density B_2 along the second Hall element **302***b*.

Each Hall element **302***a*, **302***b* includes at least five metal contacts. For example, the Hall element **302***a* includes a contact **306**, a contact **308**, a contact **310**, a contact **312** and a contact **314**, and the Hall element **302***b* includes a contact **316**, a contact **318**, a contact **320**, a contact **322** and a contact **324**.

The contacts **306**, **314** are used to supply power to the Hall element **302***a*. The contacts **308**, **312** are used to measure voltage from the Hall element **302***a* and the contact **210** provides a ground to the Hall element **302***a*.

The contacts **316**, **324** are used to supply power to the Hall element **302***b*. The contacts **318**, **322** are used to measure voltage from the Hall element **302***b* and contact **320** provides a ground to the Hall element **302***b*.

While FIGS. **2**A, **2**B and **3** show Hall elements with a single conduction path, in other embodiments, one or more Hall elements may have a separate conduction path from the other Hall elements and thereby have their own respective calibration current. In one example, each Hall elements has a separate conduction path from the other Hall elements. Each conduction path may have a separate or the same current source to generate the respective calibration current. In one example, the current sources that generate the respective calibration currents are current mirrors. In one example, the respective calibration currents are equal.

Referring to FIG. **4**, typically a magnetic sensor detects magnetic flux densities between 100 Gauss (G) to 1,000 G. Therefore, applying 20G may vary the measured magnetic flux density by roughly 2% to 20%. If the calibration current I_{cal} **126** (FIG. **1**) is bidirectional, + or −20G may be achieved doubling the signal variation. Using calibration currents with frequencies higher than a sampling frequency (e.g., >100 kHz) enables a measurement of the Hall element sensitivity, which is equal to a slope in FIG. **4** and shows Hall voltage with respect to magnetic field flux density. For example, the sensitivity of a first Hall element is:

$$sensitivity_{He1} = \frac{\Delta V_{Hall1}}{\Delta B_{ext}},$$

and the sensitivity of a second Hall element is:

$$sensitivity_{He2} = \frac{\Delta V_{Hall2}}{\Delta B_{ext}},$$

and a sensitivity mismatch is:

$$sensitivity_{mismatch} = \frac{sensitivity_{He2}}{sensitivity_{He1}} = \frac{\Delta V_{Hall2}}{\Delta V_{Hall1}},$$

where $\Delta V_{Hall\ 1}$ is the change in voltage of the first Hall element, $\Delta V_{Hall\ 2}$ is the change in voltage of the second Hall element, and ΔB_{ext} is the change in magnetic field flux density.

Variances in the measured sensitivity causing a sensitivity mismatch lead to harmonic errors. By compensating the sensitivity mismatch by a change in the Hall element biasing current and/or a mathematical factor in angle processing, the angle accuracy may be improved.

Referring to FIGS. **5**A to **5**C, examples of circuits to generate compensation signals are circuits **500***a*, **500***b*, **500***c*. The circuits **500***a*-**500***c* determine compensations signal **524***a*, **524***b*, **524***c*, which are in one embodiment, examples of compensation signals **128**.

In one example, the circuit **500***a* provides a compensation signal in the x-direction. The circuit **500***a* includes a current source **502***a* that provides a calibration current $I_{x\ cal}$ on a conduction path **504***a* to a coil **506***a*. The coil **506***a* generates a magnetic flux density $B_{x\ cal}$ that is detected by a Hall element **510***a* that is aligned along an x-axis. The coupling factor F_x is equal to $B_{x\ cal}/I_{x\ cal}$.

The output signal of the Hall element **510***a* is amplified by an amplifier **514***a* and converted from an analog signal to a digital signal by an analog-to-digital converter (ADC) **518***a*. The digital signal is a calibration signal **524***a* and represented as $B_{x\ cal,\ measure}$.

In one example, the circuit **500***b* provides a compensation signal in the y-direction. The circuit **500***b* includes a current source **502***b* that provides a calibration current $I_{y\ cal}$ on a conduction path **504***b* to a coil **506***b*. The coil **506***b* generates a magnetic flux density $B_{y\ cal}$ that is detected by a Hall element **510***b* that is aligned along a y-axis. The coupling factor F_y is equal to $B_{y\ cal}/I_{y\ cal}$.

The output signal of the Hall element **510***b* is amplified by an amplifier **514***b* and converted from an analog signal to a digital signal by an ADC **518***b*. The digital signal is a calibration signal **524***b* and represented as $B_{y\ cal,\ measure}$.

In one example, the circuit **500***c* provides a compensation signal in the c-direction. The circuit **500***c* includes a current source **502***c* that provides a calibration current $I_{y\ cal}$ on a conduction path **504***c* to a coil **506***c*. The coil **506***c* generates a magnetic flux density $B_{z\ cal}$ that is detected by a Hall element **510***c* that is aligned along a z-axis. The coupling factor F_z is equal to $B_{z\ cal}/I_{z\ cal}$.

The output signal of the Hall element **510***c* is amplified by an amplifier **514***c* and converted from an analog signal to a digital signal by an ADC **518***c*. The digital signal is a calibration signal **524***c* and represented as $B_{z\ cal,\ measure}$.

In one embodiment, the current sources **502***a*-**502***c* are the same current source. In other embodiments, the current sources **502***a*-**502***c* are current mirrors.

Referring to FIGS. **6**A to **6**C, examples of circuits to calibrate signals measured from Hall elements using the compensation signals are circuits **600***a*, **600***b*, **600***c*. The circuits **600***a*-**600***c* determine adjusted signals **612***a*, **612***b*, **612***c*, which are signals that have been calibrated using the compensation signals **524***a*-**524***c*.

In one example, the circuit **600***a* provides the adjusted signal **612***a* in the x-direction. The circuit **600***a* includes the Hall element **510***a*, which receives a detected magnetic field, $B_{ext,x}$. The output signal of the Hall element **510***a* is amplified by the amplifier **514***a* and converted from an analog signal to a digital signal **602***a* by the ADC **518***a*. The digital signal **602***a* is represented as $B_{x\ ext,\ measure}$.

In this embodiment, the digital signal **602***a* is the adjusted signal **612***a*. In this embodiment, the Hall elements **510***b*, **510***c* that are aligned along the y-axis and the z-axis are calibrated with the Hall element **510***a* along the x-axis. In other embodiments, the Hall elements may calibrate to the Hall element along the y-axis or the z-axis. In other embodiments, two Hall elements may be calibrated to each other. In still further embodiments, the Hall elements may be calibrated to a low drift current source.

In one example, the circuit **600***b* provides the adjusted signal **612***b* in the y-direction. The circuit **600***b* includes the Hall element **510***b*, which receives a detected magnetic field, $B_{ext,y}$. The output signal of the Hall element **510***b* is amplified by the amplifier **514***b* and converted from an analog signal to a digital signal **602***b* by the ADC **518***b*. The digital signal **602***b* is represented as $B_{y\ ext,\ measure}$. The digital signal **602***b* is provided to a mixer **604***b* to be mixed with the compensation signal **524***a*, **524***b*. That is, the ratio of the compensation signal **524***b* to the compensation signals **524***c* ($B_{x\ cal,\ measure}/B_{y\ cal,\ measure}$) is mixed with the signal **602***b* to provide an adjusted signal **612***b*.

In one example, the circuit **600***c* provides the adjusted signal **612***c* in the z-direction. The circuit **600***c* includes the Hall element **510***c*, which receives a detected magnetic field, $B_{ext,z}$. The output signal of the Hall element **510***c* is amplified by the amplifier **514***c* and converted from an analog signal to a digital signal **602***c* by the ADC **518***c*. The digital signal **602***c* is represented as $B_{z\ ext,\ measure}$. The digital signal **602***c* is provided to a mixer **604***c* to be mixed with the compensation signals **524***a*, **524***c*. That is, the ratio of the compensation signal **524***b* to the compensation signal **524***c* ($B_{x\ cal,\ measure}/B_{z\ cal,\ measure}$) is mixed with the signal **602***c* to provide an adjusted signal **612***c*.

Referring to FIG. **7**, an example of the IC **100** (FIG. **1**) to calibrate signals from the Hall elements is an IC **100'**. The IC **100'** includes an angle sensor **101'**, which is an example of the angle sensor **101** (FIG. **1**), and power **702** which powers the IC **100'**.

The Hall elements **102'** includes Hall elements **102'**, which are similar to Hall elements **102** (FIG. **1**); angle processing circuitry **104'**, which is similar to angle processing circuitry **104** (FIG. **1**), and calibration circuitry **108'**, which is similar to calibration circuitry **108** (FIG. **1**).

The angle sensor **101'** includes a Hall element **702***a* aligned along the x-axis and a Hall element **702***b* aligned along the y-axis. The Hall elements **702***a*, **702***b* are biased by the Hall plate biasing **706**.

The calibration circuitry **108'** includes a calibration biasing circuit **708**, which supplies the calibration current I_{cal} on the conduction path **704** to generate magnetic field flux densities at the coils **702***a*, **702***b* adjacent to their respective Hall element **702***a*, **702***b*.

Each Hall element **702***a*, **702***b* provides a signal to a multiplexor **710** which is controlled by time multiplexor logic **714**. The signals from the multiplexor are converted by an ADC **718** from analog to digital and sent to a multiplexor **712** controlled by the time multiplexor logic **714**.

The calibration circuitry **108'** also includes calibration logic **726**. The signals from the multiplexor **712** are sent to the calibration logic **726** to determine the compensation signals. The compensation signals are sent to compensation factor **730**.

In this embodiment, the signals from the Hall plate **702***a* are calibrated to the Hall plate **702***b*. Thus, the signals from the Hall plate **702***a* are mixed by a mixer **737** of the angle processing circuitry **104'** with compensation signals from the compensation factor **730** and sent to an angle processor **742** while the signals from the Hall plate **702***b* are sent directly to the angle processor **742**.

In one example, the angle processor **742** is a CORDIC (COordinate Rotation DIgital Computer). The angle processor **742** may perform various trigonometric functions that can be used to compute an angle of magnetic field. In one example, the angle processor **742** performs a function, α tan **2** (**P1**, **P2**) to determine α, the angle of the direction of the magnetic-field vector, where **P1** and **P2** are parameters. In one example, **P1** may represent signals from the Hall element **702***b* and **P2** represents signals from the Hall element **702***a*.

The angle determined by the angle processor **742** is sent to digital logic **748** and to an output stage **752**. The update timer **734** is used to control the calibration logic and the compensation factor **730** to update the calibration signals on a regular basis.

The compensation circuitry **108'** also includes a non-volatile (NV) memory **758**. In one example, the NV memory **758** stores parameters to control the update timer **734**, the compensation factor **730**, the digital logic **748** and the output stage **752**.

In some examples, the NV memory **758** store time adjustment factors and amplitude adjustment factors (PID regulator logic) for the compensation block **730** and the update timer block **734** in order to control the speed in which the compensation factor is being adjusted.

In some examples, the NV memory **758** may be used to control the digital logic **748** to adjust the angle output to fit application requirements (e.g., adjust zero angle point, adjust angle gain, adjust angle saturation and so forth).

In some examples, the NV memory **758** may be used to store configuration values for the output stage **752**, so that different interfaces may be used (e.g., SENT, PWM with various tick times, frequencies and so forth).

Elements of different embodiments described herein may be combined to form other embodiments not specifically set forth above. Various elements, which are described in the context of a single embodiment, may also be provided separately or in any suitable subcombination. Other embodiments not specifically described herein are also within the scope of the following claims.

What is claimed is:

1. An angle sensor comprising:

a first Hall element disposed on a first axis;

a second Hall element disposed on a second axis perpendicular to the first axis;

a conduction path having a first portion extending parallel to the first axis and a second portion parallel to the second axis, wherein the conduction path is not in contact with the first or second Hall elements, wherein the conduction path is configured to conduct a calibration current that generates a first magnetic flux density measured at the first Hall element and a second magnetic flux density measured at the second Hall element; and

calibration circuitry configured to:

generate one or more compensation signals based on the first and second magnetic flux densities; and

adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor.

2. The angle sensor of claim **1**, wherein the first and second Hall elements are vertical Hall elements.

3. The angle sensor of claim **1**, wherein the calibration current is 10 milliamps.

4. The angle sensor of claim **1**, wherein the first and second Hall elements are planar Hall elements.

5. The angle sensor of claim **4**, wherein the conduction path is a coil.

6. The angle sensor of claim **1**, wherein the calibration current is an alternating current.

7. The angle sensor of claim **6**, wherein a frequency of the calibration current is 100 kHz.

8. The angle sensor of claim **1**, wherein the conduction path is spaced apart from the first Hall element by about one micron.

9. The angle sensor of claim **8**, wherein the conduction path is spaced apart from the second Hall element by about one micron.

10. An angle sensor comprising:

a first Hall element disposed on a first axis;

a second Hall element disposed on a second axis perpendicular to the first axis;

a third Hall element disposed on a third axis, the third axis being perpendicular to the first axis and being perpendicular to the second axis;

a conduction path having a first portion extending parallel to the first axis and a second portion parallel to the second axis, wherein the conduction path is configured to conduct a calibration current that generates a first magnetic flux density measured at the first Hall element and a second magnetic flux density measured at the second Hall element; and

calibration circuitry configured to:

generate one or more compensation signals based on the first and second magnetic flux densities; and

adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor,

wherein the conduction path has a third portion extending parallel to the third axis.

11. The angle sensor of claim **10**, wherein the calibration current generates a third magnetic flux density measured at the third Hall element;

wherein the calibration circuitry is further configured to:

generate the one or more compensation signals based on the third magnetic flux density; and

adjust the magnetic flux measured at the third Hall element from an external magnetic field using the one or more compensation signals.

12. The angle sensor of claim **10**, wherein the conduction path is not in contact with the first, second or third Hall elements.

13. The angle sensor of claim **10**, wherein the first and second Hall elements are vertical Hall elements or planar Hall elements.

14. A method comprising:

generating a first magnetic flux density and/or a second magnetic flux density using a calibration current on a conduction path;

determining one or more compensation signals based on the first magnetic flux density measured at a first Hall element of an angle sensor disposed on a first axis and the second magnetic flux density measured at a second Hall element of the angle sensor disposed on a second axis perpendicular to the first axis;

separating the conduction path from the first and/or second Hall element by a distance; and

adjusting an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals.

15. The method of claim **14**, wherein separating the conduction path from the first and/or second Hall element by a distance comprises spacing the conduction path about 1 micron from the first Hall element.

16. The method of claim **15**, wherein separating the conduction path from the first and/or second Hall element by a distance comprises spacing the conduction path about 1 micron from the second Hall element.

17. A method comprising:

determining one or more compensation signals based on a first magnetic flux density measured at a first Hall element of an angle sensor disposed on a first axis and a second magnetic flux density measured at a second

Hall element of the angle sensor disposed on a second axis perpendicular to the first axis; and

adjusting an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals; and

determining one or more compensation signals based on a first magnetic flux density, a second magnetic flux density and a magnetic flux density measured at a third Hall element orthogonal to a first and second Hall elements.

18. The method of claim **17**, further comprising adjusting an external magnetic flux density measured at the third Hall element due to the external magnetic field using the one or more compensation signals.

19. The method of claim **17**, further comprising applying a calibration current to a first conduction path that generates the first magnetic flux density.

20. The method of claim **19**, further comprising applying a calibration current to a second conduction path that generates the second magnetic flux density.

21. The method of claim **20**, wherein the first conduction path is equal to the second conduction path.

22. An angle sensor comprising:

a first Hall element disposed on a first axis;

a second Hall element disposed on a second axis perpendicular to the first axis;

a first conduction path extending parallel to the first axis, wherein the first conduction path is configured to conduct a first calibration current that generates a first magnetic flux density measured at the first Hall, wherein the first conduction path is not in contact with the first Hall element;

a second conduction path extending parallel to the second axis, wherein the second conduction path is configured to conduct a second calibration current that generates a second magnetic flux density measured at the second Hall element, wherein the second conduction path is not in contact with the second Hall element; and

calibration circuitry configured to:

generate one or more compensation signals based on the first and second magnetic flux densities; and

adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor.

23. The angle sensor of claim **22**, wherein the first conduction path is spaced apart from the first Hall element by about one micron; and

wherein the second conduction path is spaced apart from the second Hall element by about one micron.

24. The angle sensor of claim **22**, wherein the first and second calibration currents are equal.

25. The angle sensor of claim **22**, wherein the first and second Hall elements are vertical Hall elements or planar Hall elements.

26. The angle sensor of claim **22**, wherein each of the first and second calibration currents is an alternating current.

27. The angle sensor of claim **26**, wherein a frequency of each of the first and second calibration currents is 100 kHz.

28. An angle sensor comprising:

a first Hall element disposed on a first axis;

a second Hall element disposed on a second axis perpendicular to the first axis;

a third Hall element disposed on a third axis, the third axis being perpendicular to the first axis and being perpendicular to the second axis;

a first conduction path extending parallel to the first axis, wherein the first conduction path is configured to conduct a first calibration current that generates a first magnetic flux density measured at the first Hall;

a second conduction path extending parallel to the second axis, wherein the second conduction path is configured to conduct a second calibration current that generates a second magnetic flux density measured at the second Hall element;

a third conduction path parallel to the third axis,

wherein the third conduction path conducts a third calibration current that generates a third magnetic flux density measured at the third Hall element;

wherein the calibration circuitry is configured to:

generate one or more compensation signals based on the first and second magnetic flux densities;

adjust an external magnetic flux density measured at the second Hall element due to an external magnetic field using the one or more compensation signals to reduce angle error of the angle sensor;

generate the one or more compensation signals based on the third magnetic flux density; and

adjust the magnetic flux measured at the third Hall element from an external magnetic field using the one or more compensation signals.

29. The angle sensor of claim **28**, wherein the first, second, and third Hall elements are vertical Hall elements or planar Hall elements.

30. The angle sensor of claim **28**, wherein the first, second and third calibration currents are equal.

31. The angle sensor of claim **28**, wherein the first conduction path is not in contact with the first Hall element,

wherein the second conduction path is not in contact with the second Hall element, and

wherein the third conduction path is not in contact with the third Hall element.

32. The angle sensor of claim **28**, wherein each of the first, second and third calibration currents is an alternating current.

33. The angle sensor of claim **32**, wherein a frequency of each of the first, second and third calibration currents is 100 kHz.

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